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A Study of Impact between Golf Ball and Face of Golf Club Head

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Abstract

The objective of this project is to advance the understanding of the interaction between golf ball and the face of a golf club head during impact. An impact experiment was set up by dropping golf ball on testing surfaces connected to dynamometer. High speed camera was used to find the spin rate of golf ball. Although spin rate of golf ball could not be found due to camera's low frame rate, this report found that friction coefficient between golf ball and testing surface mainly affected by the angle of testing surface and grooves on surface do not affect friction coefficient.

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0. Foreword

This is a partly done project with Konstantinos T. Georgiadis, I would like to specially thank him for his contribution.

1. Introduction

Golf is an interesting and relaxing sport that requires skills to play well. Players need to shoot accurately to achieve better results. Imparting backspin to golf ball will let golf ball stop near the point it lands rather than continue going forward. Professional golf players have rich personal experience and knowledge to decide how to impart right amount of backspin to golf ball for their goals.

1.1. Objective

The objective is to advance the understanding of the interaction between a golf ball and the face of a golf club head during impact, in particular to better understand how the spin that can be imparted to the ball during the impact is influenced by the roughness and angle of the face.

1.2. Rationale

According to a trainer at the Jim Mclean Golf Center, regarded as the top golf school in the United States, having the ability to apply backspin during a golf match has proven to improve a golfer's quality of play (McLean 2000). An in-depth study of golf backspin could help amateur golfers, as well as professionals, improve their golf game.

1.3. State of the Art

1.3.1. Current Golf Clubs

Many techniques in machining methods and material selection have successfully enhanced a golfer's ability to spin a golf ball but none of these are permitted by the USGA. For many years and still today, many golfers believe that the grooves inserted into all modern clubs enhance backspin. This is incorrect after many studies proved the grooves sole and only purpose is to shed water during the moment of impact between the golf club and the golf ball (Tannar 2015).

1.3.2. Ping-pong Ball Study

Impact behavior of ping-pong balls has been studied by University of Sydney. The experiment was done by dropping a ping-pong ball by hand at speeds up to about 10m/s normally on a force plate. A 600 fps camera was used to measure the incident speed and rebound speed of ping-pong ball. Force measured from the force plate versus time elapsed is plotted to graphs in order to obtain properties of impact (Cross 2013).

1.3.3. Golf Ball Dynamic Behavior due to Impact

Researchers have been studying the impact behavior of golf balls including contact force and time spin rate as a function of impact velocity. Experimenting by launching a golf ball horizontally to an oblique surface has previously been done. As inbound ball velocity increases, the average angular velocity of the ball will increase after impact. If a relatively smooth surface compare to rough surface is used as an impact surface, the angular velocity after impact will decrease (Arakawa et al. 2007).

1.3.4. Relevant Patents

1.3.4.1. Backspin-Enhancing Golf Club Face Patents

For enhancing backspin, the golf club's face is an important asset. Inventors have found different ways to make golf club faces that enhance golf ball backspin over last century. In a patent invented by Igarashi, the club face has relatively sharp grooves compared to conventional clubs; these sharp grooved edges resulted in more spin (Igarashi 1995). This study directly contradicts that of Ken Tanner, who stated the lesser relevance of grooves on ball spin (Tanner 2015).

In another patent invented by Thompson, providing parallel steps from the lower edge to upper edge of club face can impart backspin to the golf ball, because "a plurality of edges adapted to bite into a golf ball upon impact to impart back spin to the ball" (Thompson 1975). Kitaichi invented a golf club head with elastic intermediate applied to the club face. When launching the ball, the elastic deformation of the elastic intermediate impart excessive backspin to a golf ball due to longer contact time (Kitachi 1995).

1.3.5. Existing Devices

1.3.5.1. Spin Doctor Wedge

The Spin Doctor Wedge is created using an insert system called "Fresh Face Technology." By using a Spin Doctor Wedge, players are able to select different inserts and adjust during the golf match. The purpose of having these varying inserts is to generate a different backspin rate (Spin Doctor Golf Inc. 2015). On a side note, this golf club has been declared illegal by the United States Golf Association and is not permitted to be used by professional or amateur golfers.

1.3.6. Impact Force-time Curve

As shown in figure 1 (Russell 2011), during an impact between baseball and bat without considering energy loss, force acting on the ball gradually increases to a point where it reaches maximum value from zero after the ball get in touch with bat, then gradually decreases to zero until the ball leaves the bat. The time spent by each of these two steps are equivalent.

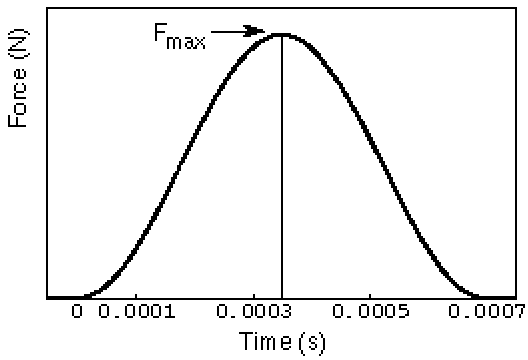

Figure 1: Impact Force-time Curve

1.3.7. Impact Calculation

Impact is a high force applied over a short time period when two or more bodies collide. To show the relationship of initial and final kinetic energy when an object makes an elastic impact with another object which is stable, in an ideal situation where energy loss to heat is negligible, energy is constant and the equation of kinetic energy can be expressed as

$$KE_i = KE_f \quad [1].$$

These express initial and final kinetic energy. Sum of kinetic energy can be expressed as the sum of linear kinetic energy and rotational kinetic energy, which is

$$KE = KE_{linear} + KE_{rotational} \quad [2].$$

Therefore, assuming that energy is conserved, (eq. 1) can be expressed as

$$\frac{1}{2}mv_i^2 + \frac{1}{2}I\omega_i^2 = \frac{1}{2}mv_f^2 + \frac{1}{2}I\omega_f^2 \quad [3],$$

where *m* is the mass of the object, *v* is the linear velocity of the object, *I* is the moment of inertia of the object and *ω* is the angular velocity of the object (Nave 2012).

To consider the force of impact, the force can be called "slow down force", and distance of deformation when objects making elastic contact can be called "slow down distance". When making elastic impact, object will be gradually slowed down to 0 speed and then bounce back off the surface from the stable object in a short time period. Therefore, the energy transfer can be considered as: kinetic energy → potential energy → kinetic energy. Maximum potential energy can be expressed as

$$PE = \int_{s_0}^{s_f} F(s) \cdot ds \quad [4],$$

where F(s) is the force acting on the object by the stable object in a function of s, which is the displacement of the object during impact. Due to constant energy, energy equations can be shown as

$$\frac{1}{2}mv_i^2 + \frac{1}{2}I\omega_i^2 = \int_{s_0}^{s_f} F(s) \cdot ds = \frac{1}{2}mv_f^2 + \frac{1}{2}I\omega_f^2 \quad [5].$$

1.3.8. Terminal Velocity of Golf Ball when Free Fall

When considering free fall with air resistance, equation for terminal velocity would be

$$v_t = \sqrt{\frac{2mg}{C\rho A}} \qquad [6],$$

where C is the numerical drag coefficient, ρ is the air density and A is the cross-sectional area for falling object. In standard atmosphere, the air density is 1.29kg/m^3. For a sphere like golf ball, drag coefficient is 0.47. For a standard golf ball of mass 46g and radius 42.7mm, terminal velocity of free fall is 16.1m/s (Nave 2012).

1.4. Approach

To study how the impact with golf club surfaces influence the spin rates, golf ball will be dropped from different heights on exemplar metal surfaces prepared in the manufacturing labs that are fixed to a piezo electric dynamometer. And by varying the angle of club face, and club face surface roughness. Data required was obtained by setting up an impact experiment. Then, graphs could be plotted to show if relationships between these variables exist. Finally, relationships could be represented by equations generated from the graphs and data.

2. Method

2.1. Manufacture Impact Testing Surfaces

To test if grooves on golf club will affect golf spin rate after impact, two surfaces were manufactured. Material of the two surfaces is 6061 T6 aluminum. Modern golf club surfaces are made of stainless steel, titanium, tungsten, beryllium nickel, beryllium copper, or combinations of these metals. 6061 T6 aluminum was chosen because of its availability, and 6061 T6 aluminum is easier to machine than stainless steel.

An aluminum plate without grooves and another plate with grooves were manufactured as figure 2 and 3. These plates were manufactured with screw holes that match the dynamometer it would be attached on. Grooves are machined identical to grooves on golf club head.

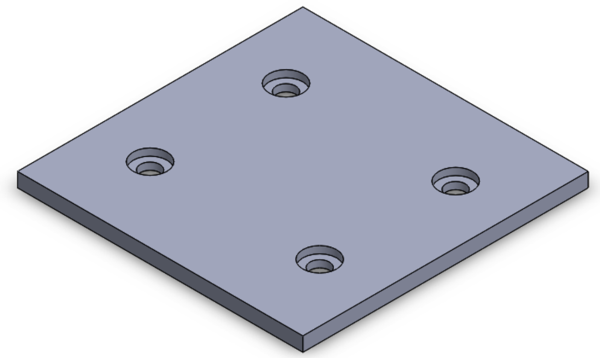

Figure 2: Ungrooved Testing Surface

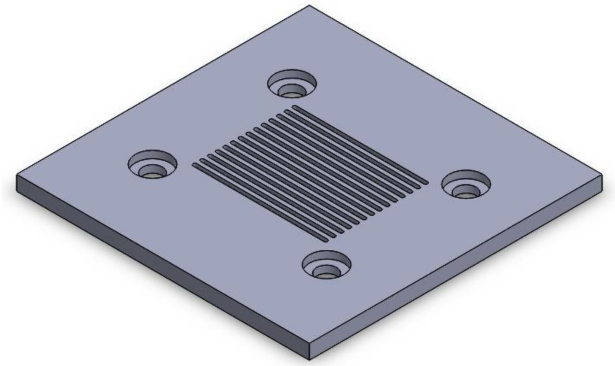

Figure 3: Grooved Testing Surface

2.2. Data Acquisition from Dynamometer

2.2.1. Dynamometer

In order to analyze impact between golf ball and testing surfaces, force generated from impact needed to be acquired. To achieve that, testing surface was bolted on Kistler dynamometer (Type 9275B). Dynamometer is a device that measures forces of three orthogonal directions that acting on it. Force directions are shown as figure 4. When there is force acting on dynamometer, the voltage generated from amplifier connected to dynamometer is changed. The unit of amplifier is mechanical unit per volt, and the scale of amplifier can be changed. After dynamometer is bolted with testing surface and lifted up with certain angle for testing, amplifier is reset so voltage generated from forces currently acting on it will show as zero.

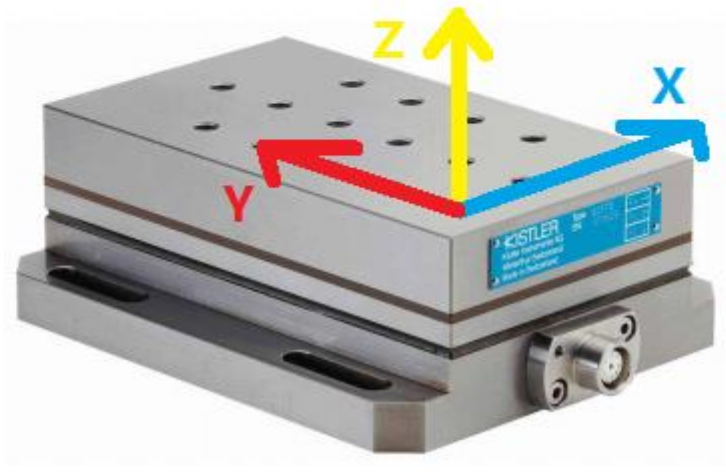

Figure 4: Dynamometer and Its Force Axes

2.2.2. Data Acquisition

2.2.2.1. Data Acquisition Device

Data acquisition device acts as the interface between a computer and signals from the outside world. It primarily functions as a device that digitizes incoming analog signals so that a computer can interpret them. NI USB-6009 was used as data acquisition device. Data acquisition device was connected to dynamometer amplifier and computer. Device was connected to three channels of amplifiers separately, which are X, Y and Z direction voltage generated from the amplifier.

2.2.2.2. Data Acquisition Software

Voltage reading from amplifier could be collected by using data acquisition software. LabVIEW software was chosen to program a virtual instrument as shown in figure 5 to achieve the aim. Based on scale chosen on amplifier, LabVIEW program can convert numerical value of voltage to numerical value of force. It can plot graphs of X, Y and Z direction forces of dynamometer once voltages generated from amplifier are higher than zero after golf ball impact at testing surface. The data acquisition rate is set at 100 kHz, which means data will be collected every 0.01ms.

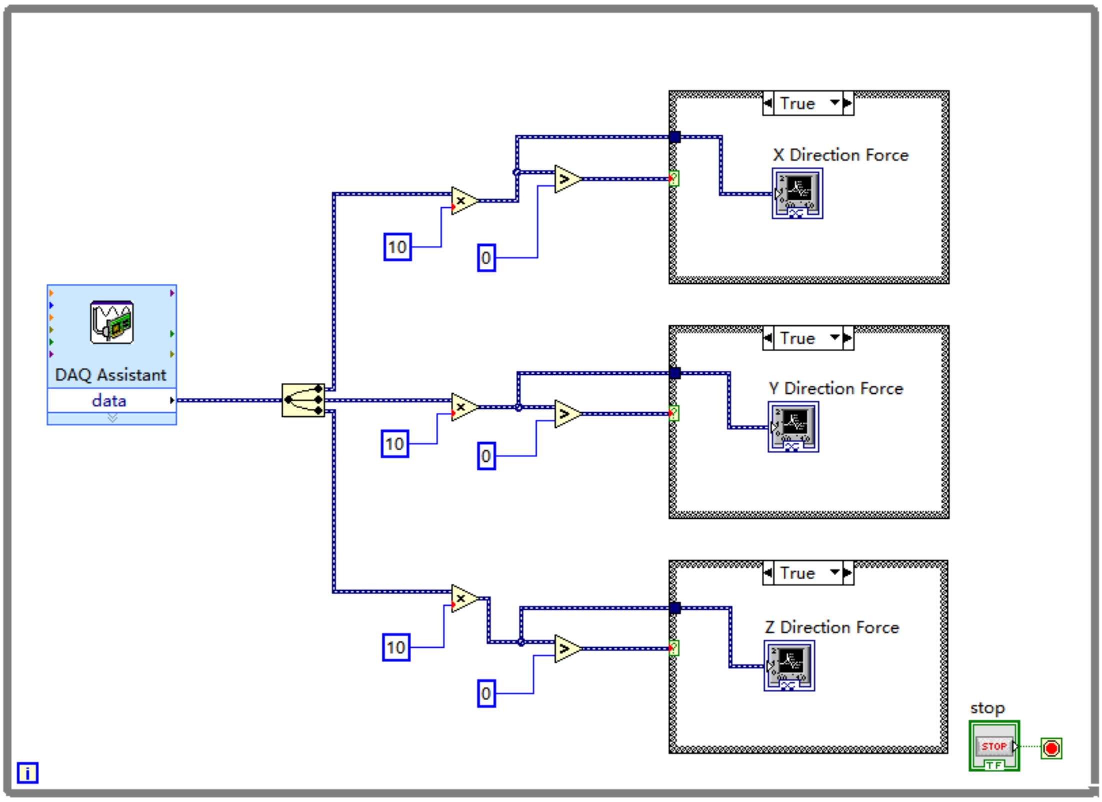

Figure 5: LabVIEW Block Diagram

2.3. Spin Rate of Golf Ball

To study the spin rate of golf ball after impact, it is impossible to observe with naked eyes. Instead, high speed camera was needed to record videos of the test. The high speed camera used in the experiment was Sony FDR-X1000V 4K Action Cam. This camera has frame rate of 240 frames per second. Its frame rate might be too low compared to cameras used in experiments in state of the art section. Therefore, blur of golf ball might appear in videos.

Black line was drawn around the golf ball to show the angle of it in videos. Change of angle divided by time interval is the spin rate:

$$\omega = \frac{\theta_2 - \theta_1}{T_2 - T_1} \qquad [7],$$

where θ is the angle of golf ball and T is the time in the video. Angular velocity could be found by using this equation if video is clear enough.

2.4. Releasing Golf Ball

2.4.1. Releasing with Minimum Spin

To get a good test result of golf spin rate after impact, it is important to drop the golf ball without imparting any spin. This is difficult because mechanical ways of dropping will cause spin easily due to friction, such as clamps releasing. To improve dropping, use vacuum to hold the golf ball before releasing will cause minimum spin due to little friction from other objects. Therefore, card board tube was used to keep the golf ball suspending by applying a partial vacuum to the tube. Golf ball could be released with minimum spin by using this technique.

2.4.2. Testing Location

Test location was chosen at first floor in WPI Washburn Shops. Outside was not chosen to be test location since wind could severely affect golf ball's free fall by making it deviate from testing surface. Golf ball was released at the balcony on second floor. The distance between releasing point and testing surface is 4.1 meters.

2.5. Testing Setup

To set up for testing, dynamometer, amplifier, data acquisition device and computer were connected. Card board tube was taped on the wall of the balcony. Then simple pretest was carried out to adjust the position of dynamometer so golf ball will hit the center of testing surface. Dynamometer was lifted up at angles of 42 degree or 48 degree with the same triangle block.

2.6. Testing Procedure

After test was set up, it needed to be run by two persons. One person was in charge of releasing the golf ball on second floor, the other person needed to run virtual instrument, record the data and graphs collected from virtual instrument, and show signs to high speed camera to mark the number of this release and whether this release is successful or not in order to avoid confusion when analyzing the videos. Releasing via each testing angle of dynamometer with each testing surface will be repeated for 10 times to make sure the data collected was enough and accurate for analysis.

2.7. Plot Force Graphs

To analyze forces generated from impact, data collected from the LabVIEW was transferred to Excel. Data were separated into three groups, they are surface without grooves at 42°, surface with grooves at 42° and surface with grooves at 48°. Each group has 10 experiment samples and they are averaged to get the final data in order to plot the accurate force graph. Then forces in X and Z directions are obtained and ready to be compared.

3. Results

3.1. Data Acquisition

Force graphs were generated from LabVIEW during test. X axis is time in unit of second, and Y axis is force in unit of Newton. Figure 6 is an example of graphs collected during data acquisition.

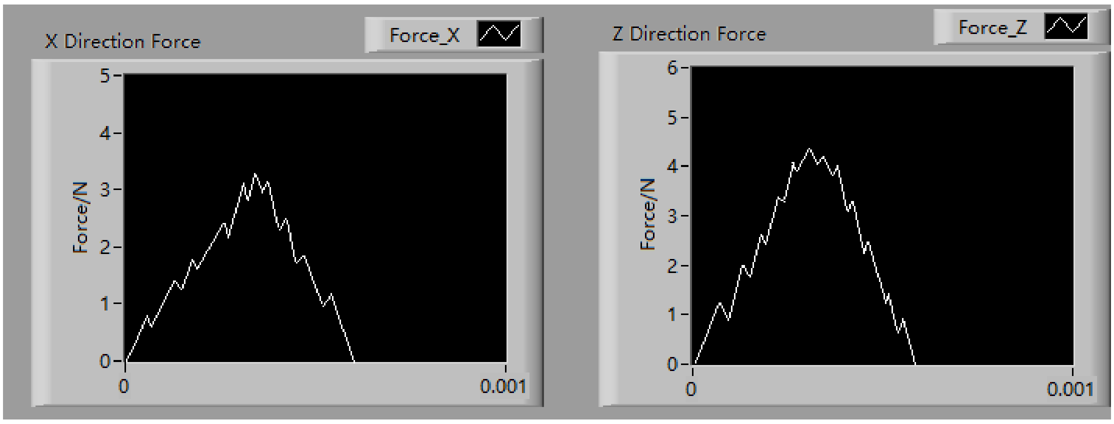

Figure 6: Force-time Graph Plotted by LabVIEW

In addition to graphs, numerical data were collected and exported to Excel. Table 1 is a part of example of Excel files collected from experiment. Left column is time in unit of second and right column is X direction force in unit of Newton.

0.000 00	0.0000
0.000 01	0.1243
0.000 02	0.2527
0.000 03	0.3738
0.000 04	0.4276
0.000 05	0.5421
0.000 06	0.6613
0.000 07	0.7834
0.000 08	0.7543
0.000 09	0.7525
0.000 10	0.9234
0.000 11	1.0358

Table 1: Example of Collected Excel Files during Experiment

3.2. Data Analysis

As mentioned in method section, force-time graphs were plotted to clearly represent information about impact between golf ball and testing surfaces. Each graph in following sections has two marked point. One is the point where force reaches its maximum value, the other is the point where impact ends.

3.2.1. Surface at 42 °Angle without Grooves

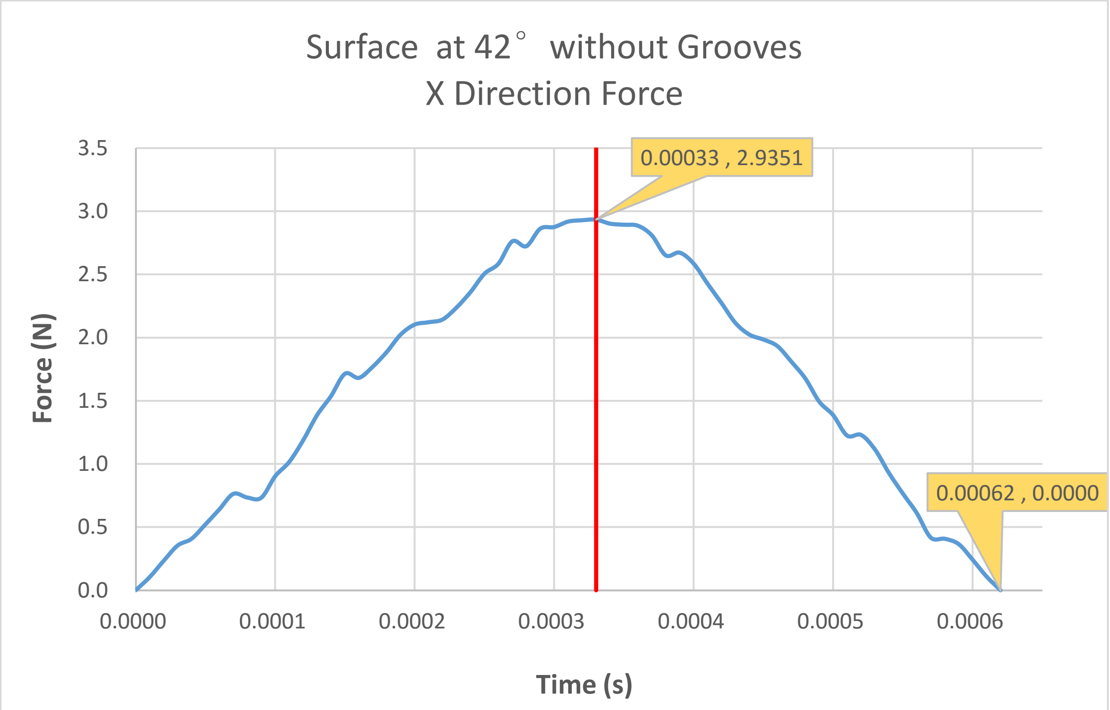

Figure 7: X Direction Force on Surface at 42 °without Grooves

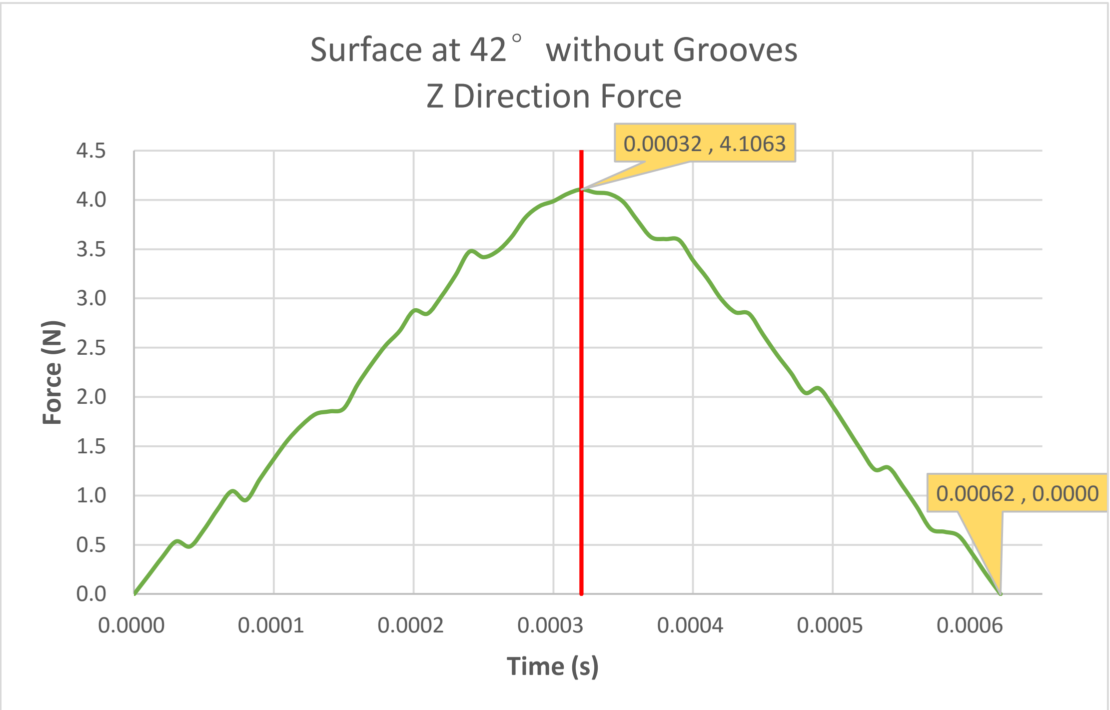

Figure 8: Z Direction Force on Surface at 42 °without Grooves

Force in X direction reaches its peak value, 2.94N, at 0.33ms after impact begins. Then it takes 0.29ms for force to reach zero.

Force in Z direction reaches its peak value, 4.11N, at 0.32ms after impact begins. Then it takes 0.3ms for force to reach zero.

Friction coefficient can be calculated using max X direction force divided by max Z direction force, which is 0.715.

3.2.2. Surface at 42 °Angle with Grooves

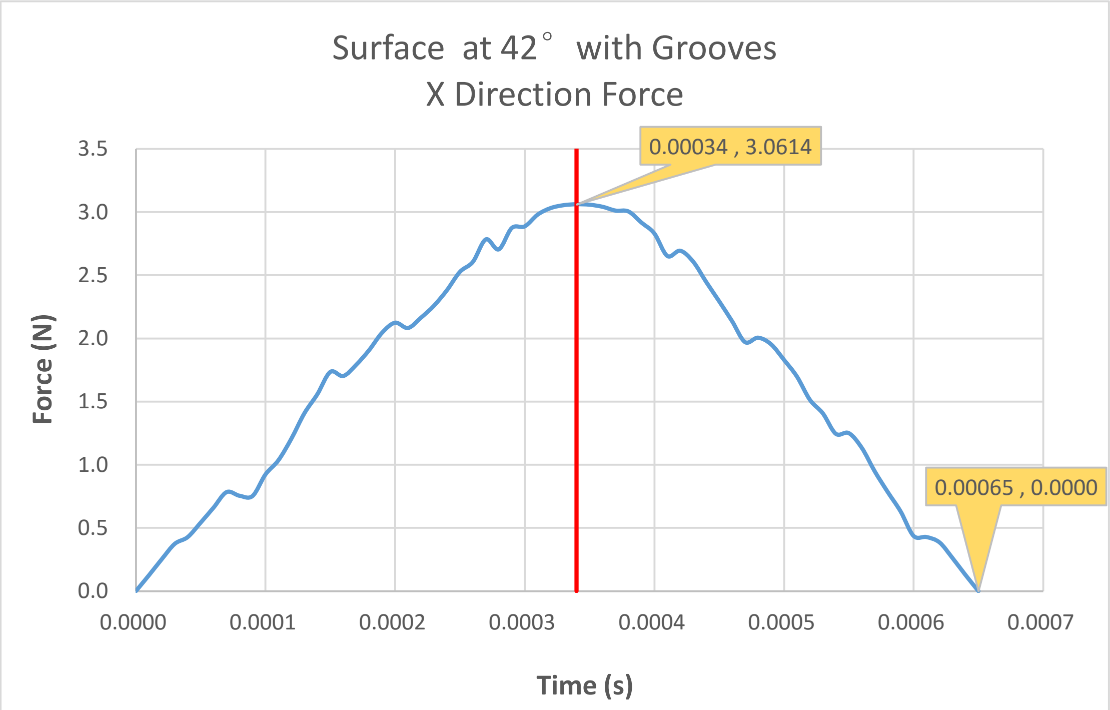

Figure 9: X Direction Force on Surface at 42 °with Grooves

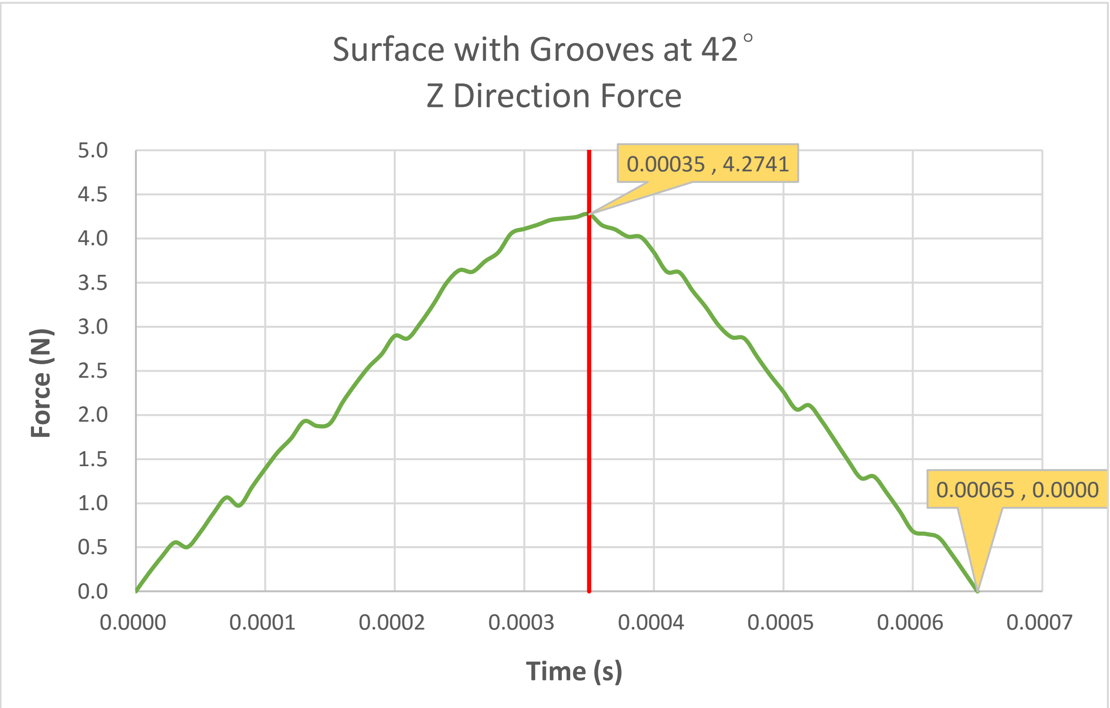

Figure 10: Z Direction Force on Surface at 42 °with Grooves

Force in X direction reaches its peak value, 3.06N, at 0.34ms after impact begins. Then it takes 0.31ms for force to reach zero.

Force in Z direction reaches its peak value, 4.27N, at 0.35ms after impact begins. Then it takes 0.3ms for force to reach zero.

Friction coefficient can be calculated using max X direction force divided by max Z direction force, which is 0.716.

3.2.3. Surface at 48 °Angle with Grooves

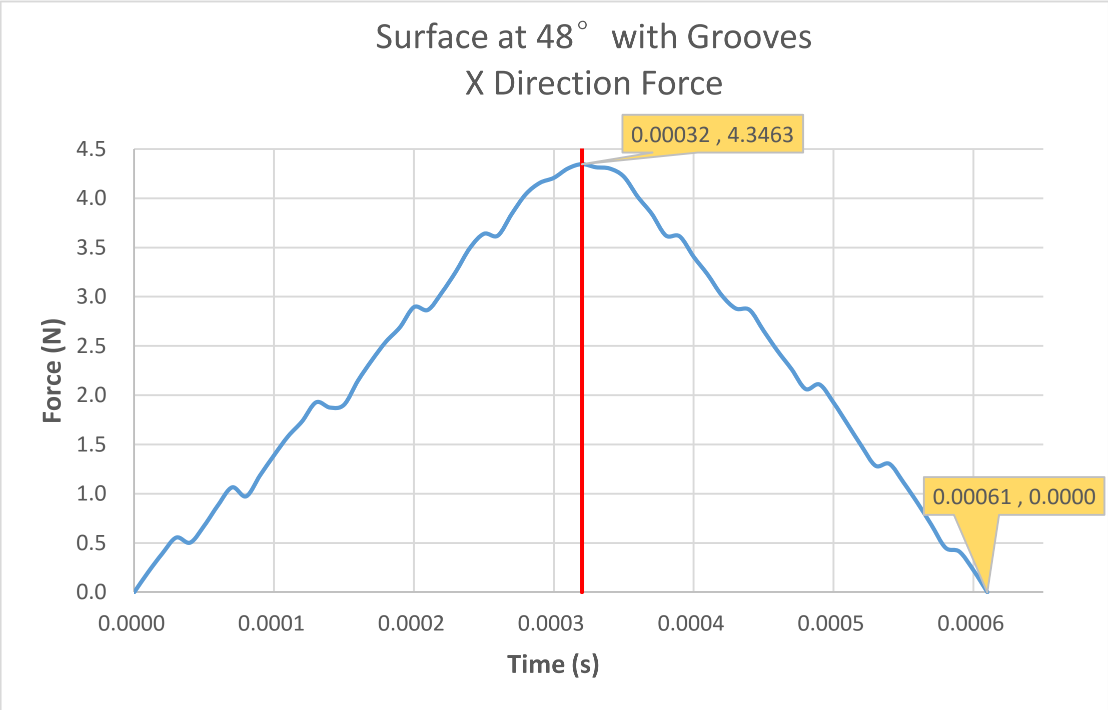

Figure 11: X Direction Force on Surface at 48 °with Grooves

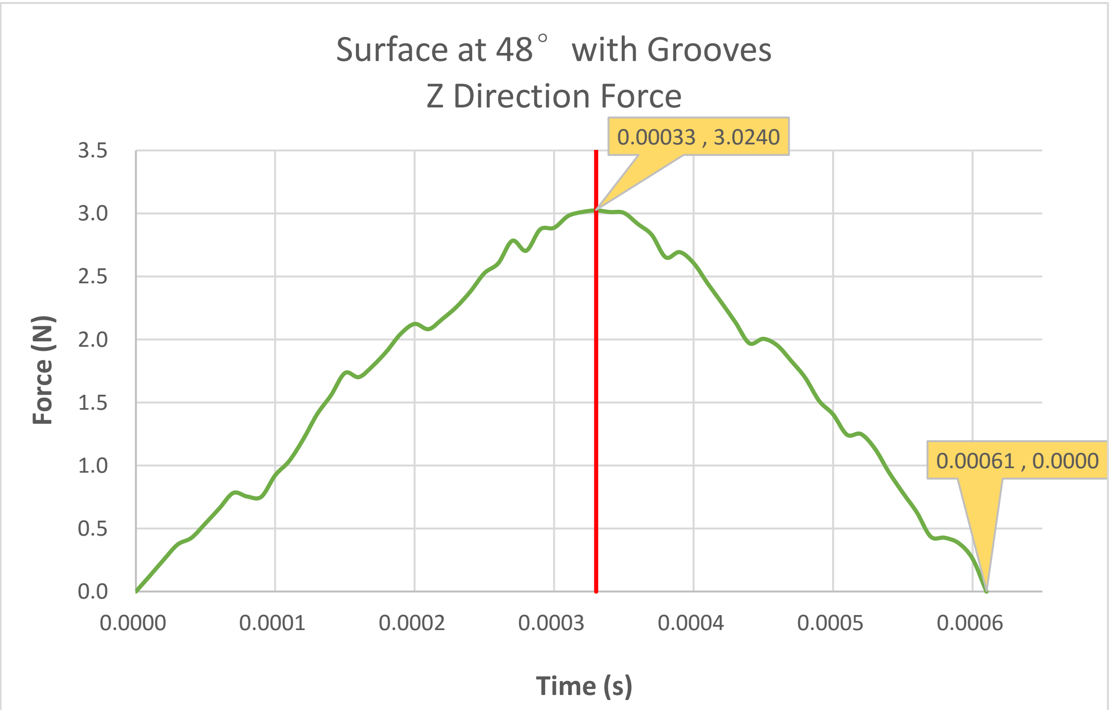

Figure 12: Z Direction Force on Surface at 48 °with Grooves

Force in X direction reaches its peak value, 4.35N, at 0.32ms after impact begins. Then it takes 0.29ms for force to reach zero.

Force in Z direction reaches its peak value, 3.02N, at 0.33ms after impact begins. Then it takes 0.28ms for force to reach zero.

Friction coefficient can be calculated using max X direction force divided by max Z direction force, which is 1.44.

3.3. Coefficient of Variation

Calculate the coefficient of variation (CV) is helpful to know the repeatability of this experiment. Coefficient of variation equals to standard deviation divided by mean and times 100%. Coefficient of variation of friction coefficient is calculated because friction coefficient is obtained from two experiment results and thus would be more reliable.

Surface at 42° Angle without Grooves			
Test No.	Max X Direction Force (N)	Max Z Direction Force (N)	Friction Coefficient
1	2.8412	4.0312	0.7048
2	2.9513	4.1254	0.7154
3	2.9863	4.1567	0.7184
4	3.0154	4.2345	0.7121
5	2.9433	4.1152	0.7152
6	2.9876	4.1515	0.7196
7	2.9184	4.0453	0.7214
8	2.9014	4.0817	0.7108
9	2.8674	4.0314	0.7113
10	2.9391	4.0902	0.7186
S.D.			0.0051
Mean			0.7148
CV			0.71%

Table 2: Coefficient of Variation Calculation 1

Surface at 42° Angle with Grooves			
Test No.	Max X Direction Force (N)	Max Z Direction Force (N)	Friction Coefficient
1	2.9675	4.2410	0.6997
2	3.0776	4.2852	0.7182
3	3.1126	4.2965	0.7245
4	3.1417	4.3043	0.7299
5	3.0696	4.2750	0.7180
6	3.1139	4.3013	0.7239
7	3.0447	4.2651	0.7139
8	3.0277	4.2515	0.7121
9	2.9937	4.2512	0.7042

10	3.0654	4.2703	0.7179
S.D.			0.0092
Mean			0.7162
CV			1.29%

Table 3: Coefficient of Variation Calculation 2

Surface at 48° Angle with Grooves			
Test No.	Max X Direction Force (N)	Max Z Direction Force (N)	Friction Coefficient
1	4.2524	2.9489	1.4420
2	4.3625	3.0431	1.4336
3	4.3975	3.0744	1.4304
4	4.4266	3.1522	1.4043
5	4.3545	3.0329	1.4358
6	4.3988	3.0692	1.4332
7	4.3296	2.9630	1.4612
8	4.3126	2.9994	1.4378
9	4.2786	2.9491	1.4508
10	4.3503	3.0079	1.4463
S.D.			0.0150
Mean			1.4375
CV			1.04%

Table 4: Coefficient of Variation Calculation 3

Therefore, the average coefficient of variation of friction coefficient is 1.01%.

3.4. Spin Rate of Golf Ball

To find out the spin rate of golf ball, high speed camera videos were analyzed frame by frame. However, golf ball itself was blurry and the black line drawn on it could not be seen in the videos. Therefore, spin rate of golf ball could not be found. Multiple shooting ways were tried to cancel blur, such as shooting at far distance and cover the light from background, but there was no improvement. Therefore, the problem might be the performance of high speed camera. 240 frames per second camera was used in the experiment. The fps of this camera might be too low compare to professional high speed cameras, which have 600 to 800 fps. Figure 13 shows how blurry the golf ball is in the video.

Figure 13: Blurry Golf Ball in Video

4. Discussion

4.1. Force-time graph

Force-time graphs show that the forces in X and Z directions of dynamometer gradually increasing to points where they reached maximum value from zero after the golf ball get in touch with the test surface, then gradually decreasing to zero until the golf ball leaves the test surface. This shape is similar to the impact curve in section 1.3.6. However, force graphs generated from test have jagged fluctuations, which is different from figure 1. When test surface was kept pressing with certain force, there was no jagged fluctuations appear in the graph. Therefore, jagged fluctuations appear in the force graphs might because of the resonance generated from impact from inside dynamometer or the block which lifted up dynamometer.

To improve the experiment by trying to decrease the resonance from impact, as shown in figure 14, a design for the base of dynamometer is brought out. This base has bolt holes that match the dynamometer. By tightening the dynamometer and base together, resonance could decrease. In addition, dynamometer angles could be changed using this base. These angles are standard golf club angles.

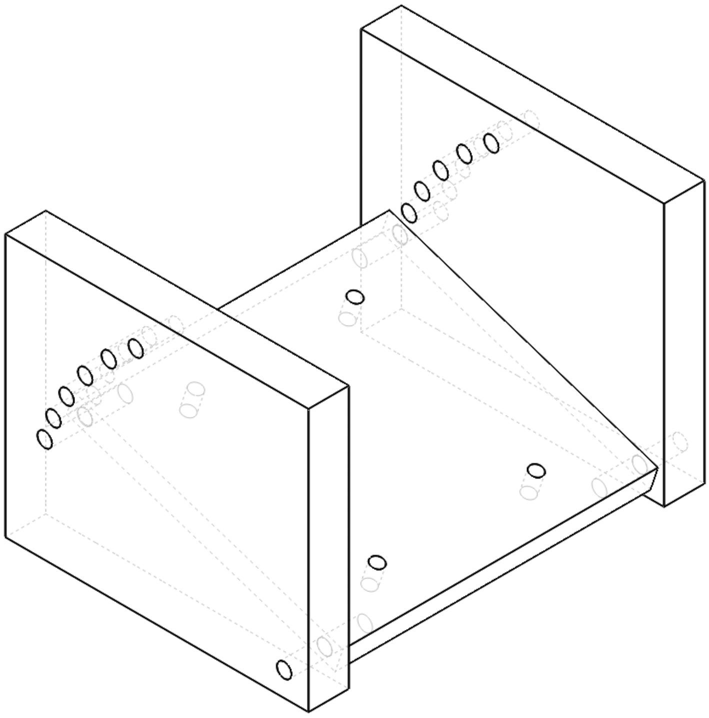

Figure 14: Design for Base of Dynamometer

4.2. Compare Impact Graphs

By comparing graphs to each other in section 3.2, intuitive information about force and time for impact can be drawn. Angle of testing surface could cause difference between forces. At 42 °angle, X direction force is relatively small compared to Z direction force. This is just the opposite of 48 °angle, where X direction force is higher than Z direction force. Grooves could also lightly affect impact forces. For surfaces at 42 °angle, forces on grooved surface are little bit higher than forces on ungrooved surface.

Consider the aspect of time, graphs show the contact time for these impacts to be about 0.6 milliseconds. In addition, all three pairs of graphs show that the time for force to reach its peak value is longer than the time it needs to decrease to zero from peak. The energy loss between inelastic impacts might be the reason for this phenomenon.

4.3. Friction Coefficient

As calculated in section 3.2, friction coefficients of ungrooved and grooved surfaces at 42 °have similar values, which are 0.715 and 0.716. This proves that grooved surface does not cause stronger friction act on golf ball than ungrooved surface.

Grooved surface at 48 °has friction coefficient of 1.44, which is higher than friction coefficient of 0.716 when grooved surface is at 42 °. Therefore, angle of testing surface is a main factor that influence the friction coefficient between golf ball and testing surface.

4.4. Repeatability

As shown in section 3.3, the coefficient of variation was calculated for repeatability. The average coefficient of variation of friction coefficient is 1.01%, which means the variation of data is very small. Therefore, the experiment has a very high repeatability.

5. Conclusions

1. Friction coefficient between golf ball and testing surface mainly affected by the angle of testing surface. Grooves do not affect friction coefficient.
2. Results indicated that the time for impact force to reach its peak value is longer than the time it needs to decrease to zero from peak. This might be caused by energy loss during impact.
3. Repeatability of this experiment is very high.
4. To find out the spin rate of golf ball, high speed camera needs to have frame rate higher than 240 fps in order to shoot clear videos.

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